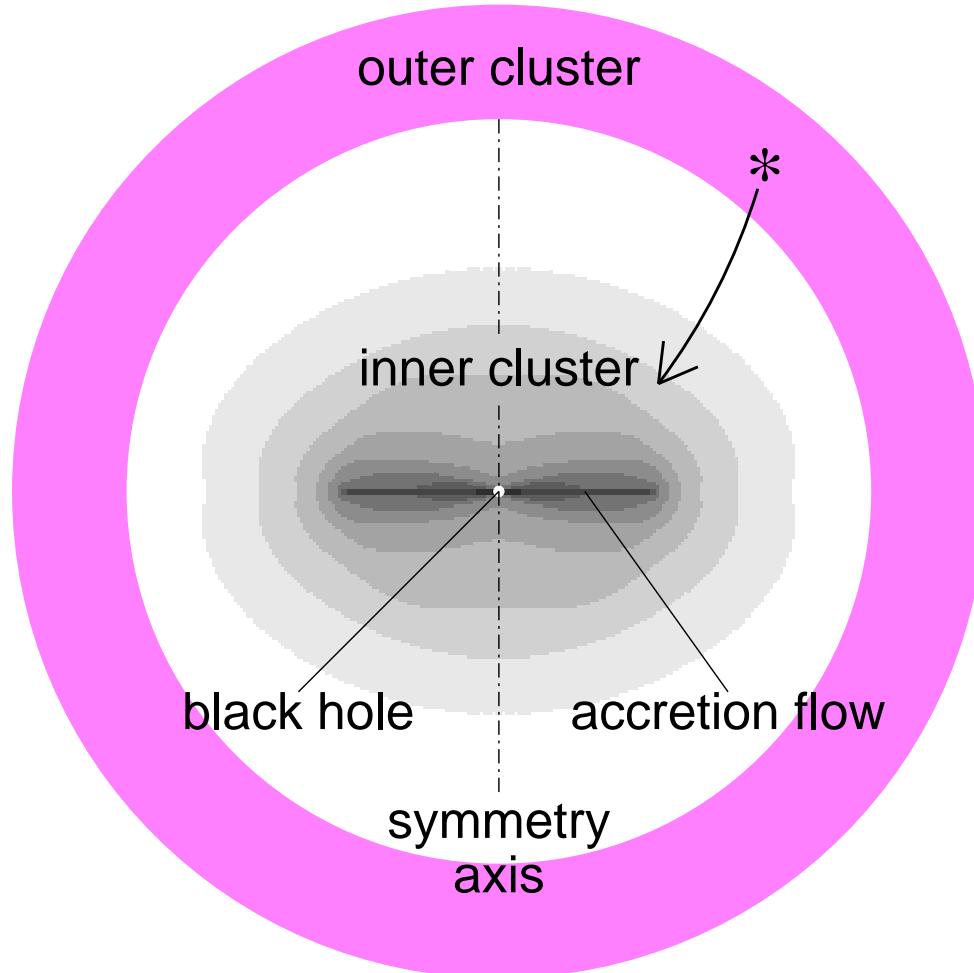


*Long-term orbital interaction  
between stars and a massive BH  
surrounded by an accretion disc*

V. Karas (Prague), L. Šubr (Bonn)

# Model

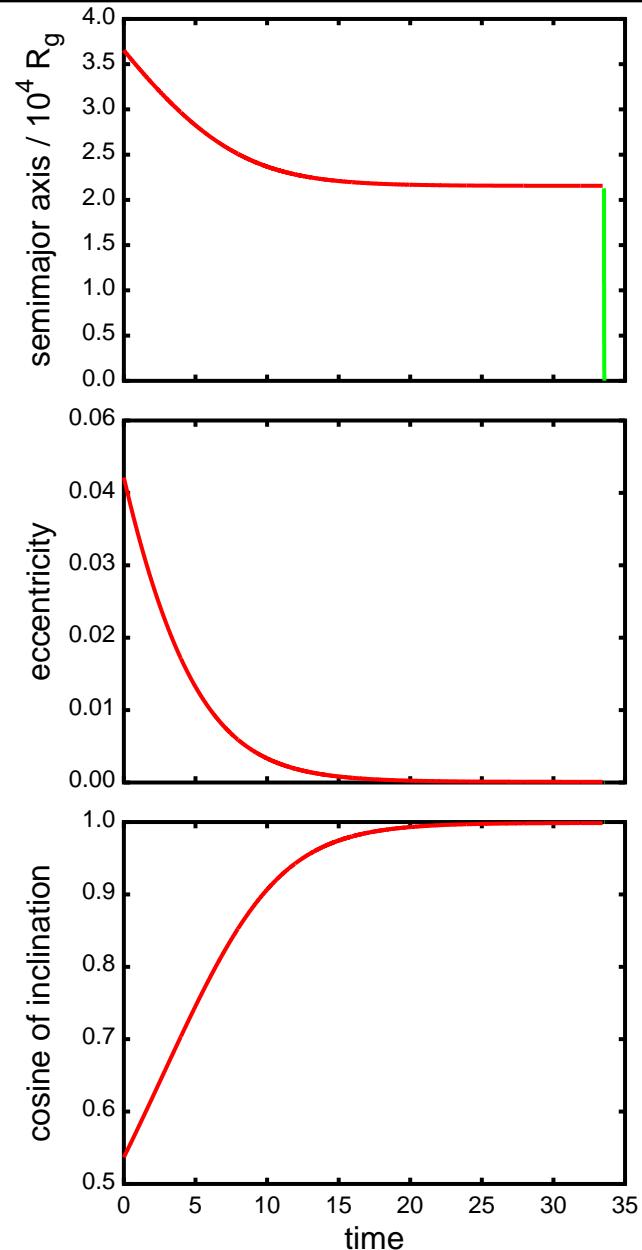


- Black hole  
 $M_{\text{BH}} \approx 10^3 - 10^8 M_{\odot}$
- Accretion flow  
 $\Sigma_d \propto r^s$   
 $R_d \approx 10^4 R_g \approx 0.1 \text{ pc}$
- ‘Outer’ cluster  
 $n(r) = n_0(r/r_h)^{-7/4}$   
 $r_h \approx 10 \text{ pc}$   
 $n_0 \approx 10^6 - 10^8 \text{ pc}^{-3}$
- ‘Inner’ cluster...

# Individual orbits

## Two phases of orbital evolution:

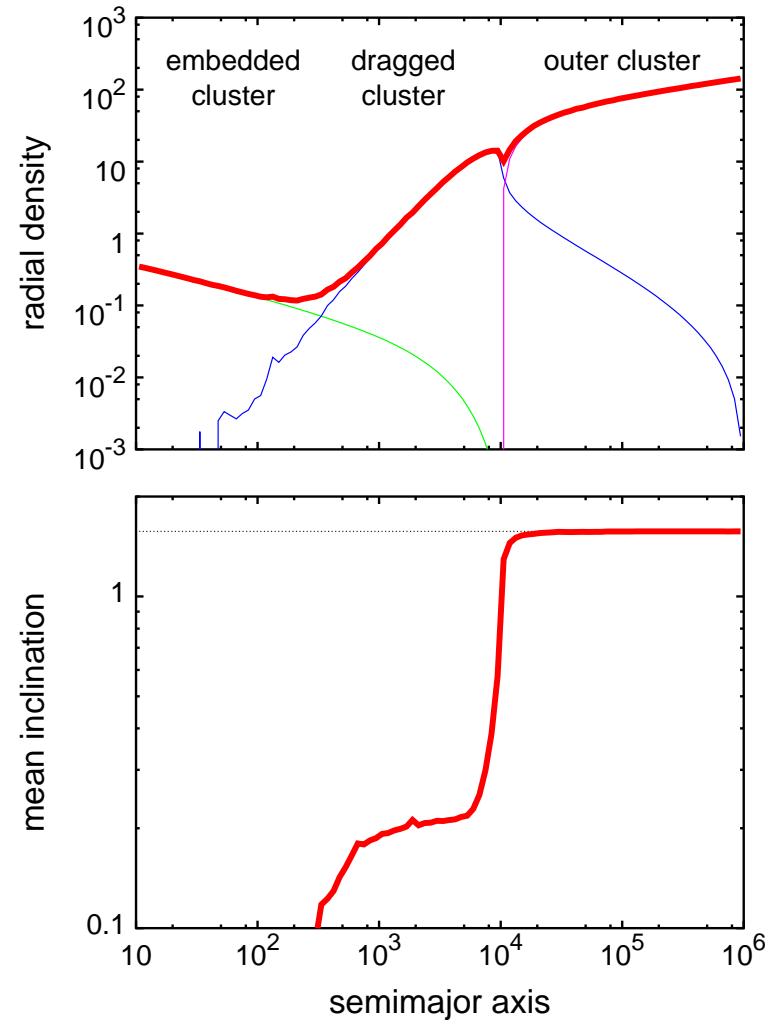
- Star-disc collisions → gradual decay towards a circular orbit and corotation with the disc
- Different modes of migration of orbits embedded in the disc
  - opening a gap (large stellar masses, thin disc)
  - accretion onto star (stronger interaction → faster decay)



Syer, Clarke & Rees (1991); Šubr, Karas & Huré (2004)

# A stationary cluster

- Outer cluster: a reservoir
- Inner cluster: becomes flattened
- Size of the inner cluster  $\simeq$  the disc outer radius
- Distribution of semi-major axes: a broken power-law



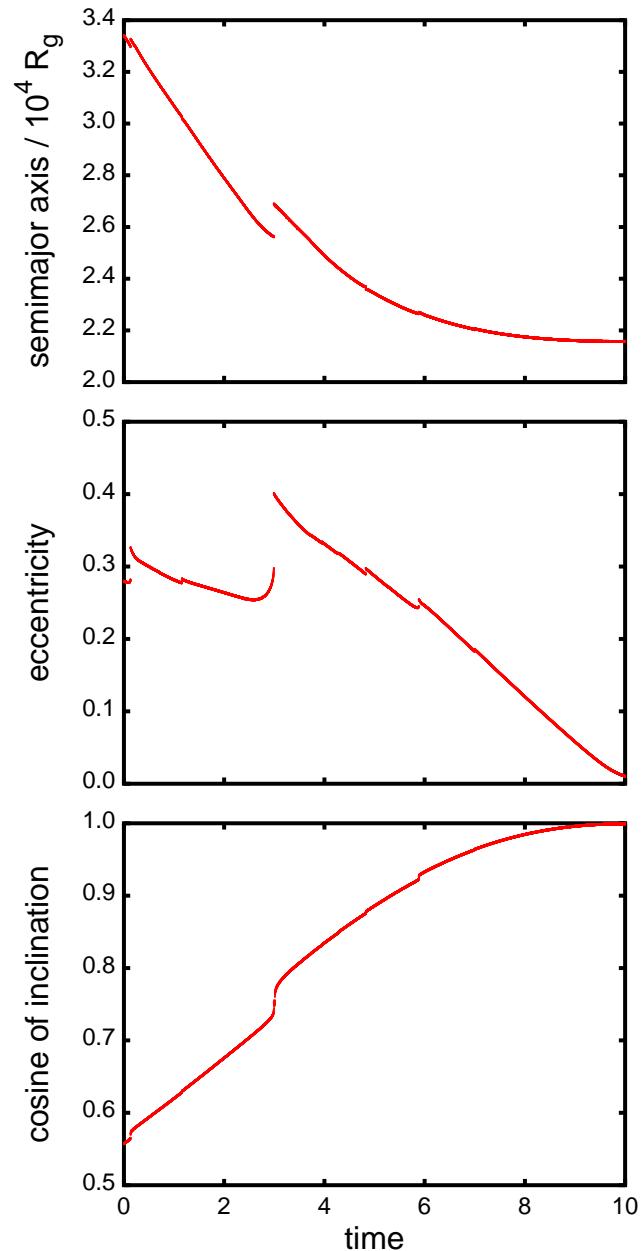
# Effects of the disc gravity

...with the gravitational effect of the disc taken into account.

New features:

- Jumps of orbital parameters occur in resonance.
- Passages through the disc are more frequent.

Expected also for binary BH.



# Time-scales

$$T_{\text{K}} = \frac{4}{3} \frac{M_{\text{BH}}}{M_{\text{d}}} \left( \frac{R_{\text{d}}}{a} \right)^3 P$$

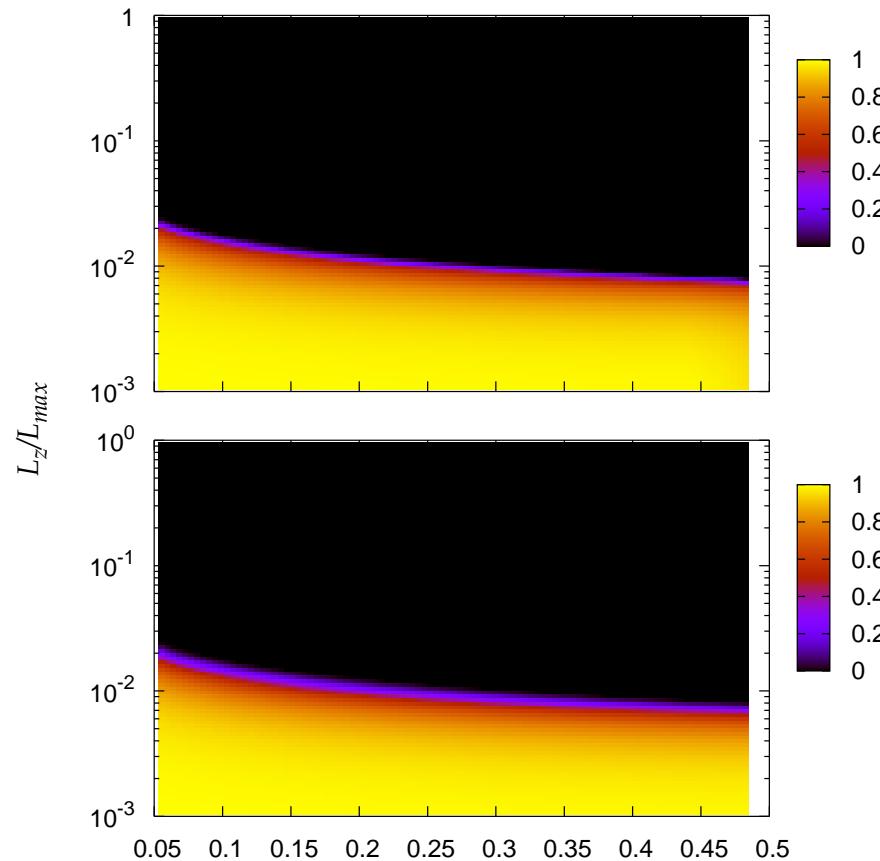
$$T_{\text{E}} = \frac{1}{3} \frac{a(1 - e^2)}{R_{\text{g}}} P$$

$$\frac{T_{\text{K}}}{T_{\text{E}}} = 4 \frac{M_{\text{BH}}}{M_{\text{d}}} \left( \frac{R_{\text{d}}}{a} \right)^3 \frac{R_{\text{g}}}{a(1 - e)} \sqrt{1 - e^2} (1 + e)$$

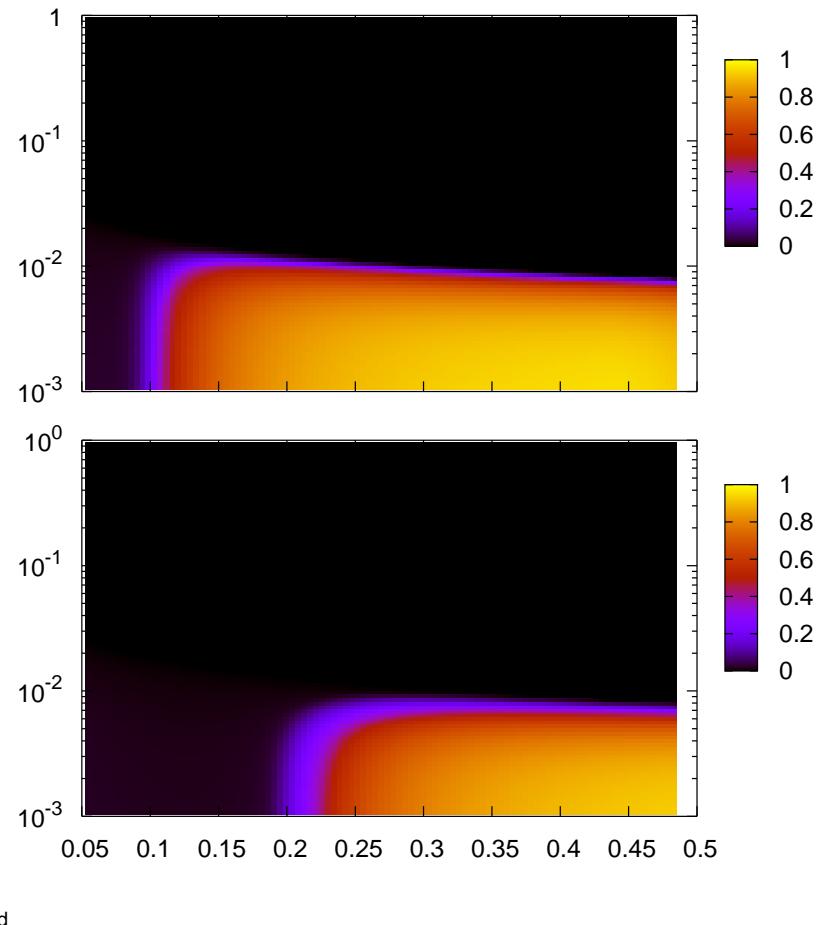
$$T_{\text{d}} = \frac{M_*}{M_{\text{d}}} \frac{R_{\text{p}}}{a} \left( \frac{R_{\text{d}}}{R_*} \right)^2 P$$

# Effect of pericenter advance

Newtonian pot. + disc



with GR pericenter advance

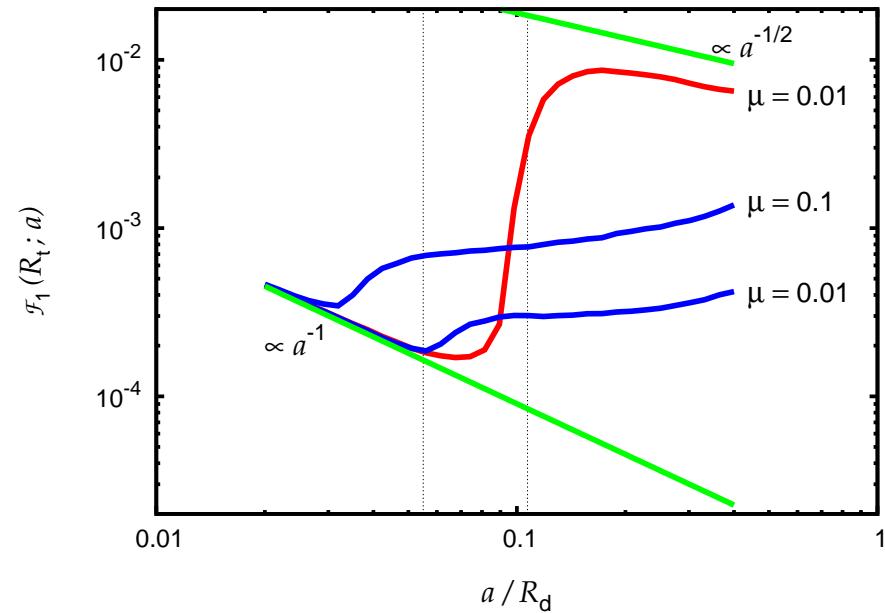


Fraction of stars getting in the loss cone because of eccentricity oscillations.

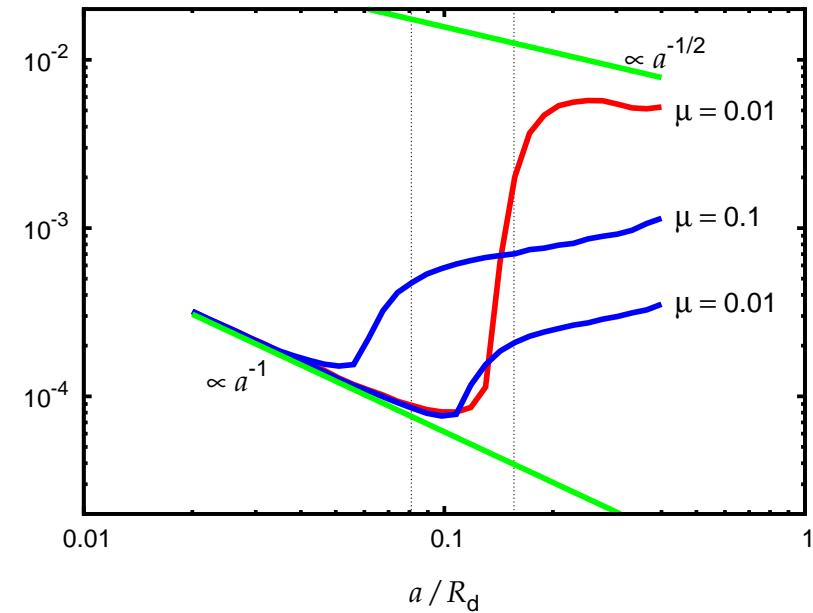
# Example: Growth of MBH

Fraction of stars that plunge below the BH tidal radius.

$$M_{\text{BH}} = 10^4 M_{\odot}$$



$$M_{\text{BH}} = 10^5 M_{\odot}$$

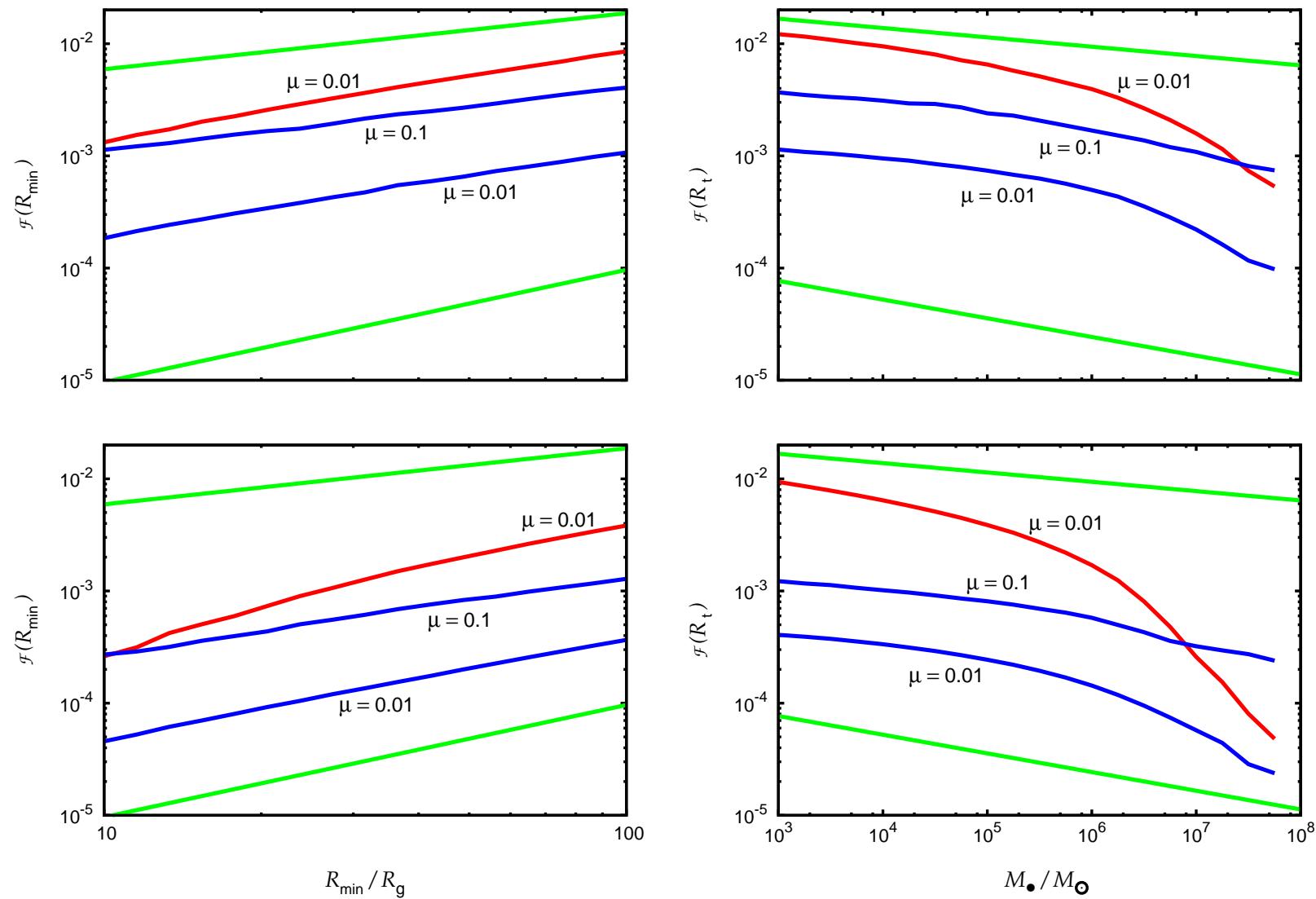


**Red** – PN1 approximation for the central mass; the outer cluster neglected.

**Blue** – the outer stellar cluster taken into account.

**Green** – analytical power-law estimates.

# Example: Growth of MBH



Fraction of stars that reach their orbit pericentres below  $R_{\min}$ .

# Conclusions

Kozai's mechanism increases the probability stars get close to MBH. More efficient for IMBH than for SMBH.

- Feeding the black hole

Rate of stars getting into the MBH tidal radius

- Modifying the inner accretion flow

Exchange of energy and angular momentum with star cluster)

- GW signal from inspiralling stars

The effect of the drag acting on the 'satellite' stars

- Modifying the cluster structure

Flattening the stellar cluster, changing the velocity dispersion near BH

# Details of the method

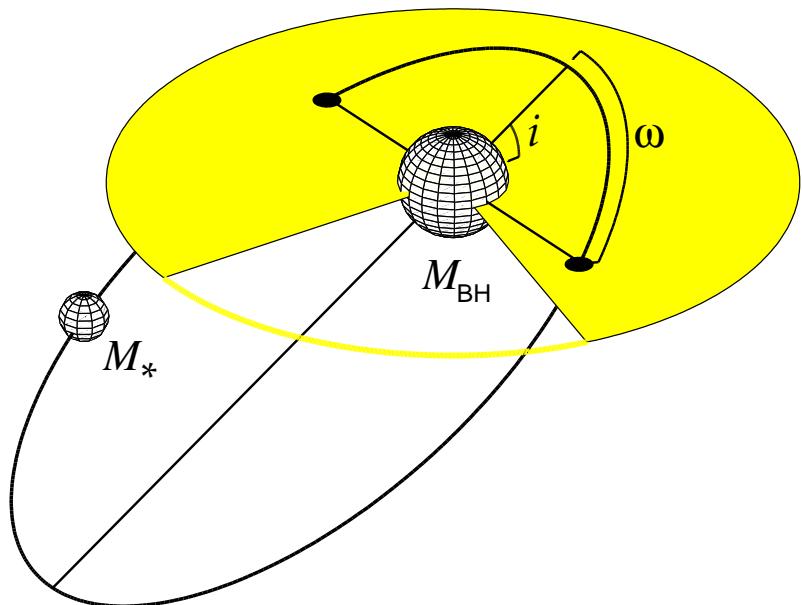
Two-body Hamiltonian,

Cartesian coordinates:

$$\mathcal{H} = \frac{1}{2} (v_1^2 + v_2^2 + v_3^2) - \frac{\mathcal{G}(m_0 + m_1)}{\sqrt{x_1^2 + x_2^2 + x_3^2}}$$

Delaunay variables:

$$\mathcal{H} = -\frac{\mathcal{G}^2(m_0 + m_1)^2}{2L^2}$$



$$L = \sqrt{\mathcal{G}(m_0 + m_1)a} \quad l = M$$
$$G = L \sqrt{1 - e^2} \quad g = \omega$$
$$H = G \cos i \quad h = \Omega$$

# Contour analysis, $\bar{V}(e, \omega) = \text{const}$

